Canopy gap characteristics and its influence on the regeneration of broad-leaved Korean pine forests in Changbai Mountain[1]

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Abstract With the concern of regeneration, characteristics of canopy gaps in broad-leaved Korean pine forest were studied. The areas of actual gap, expanded gap and maximum gap were analyzed respectively. The species composition, number, origin, decayed class and sizes of gap makers were studied comprehensively. The comparative studies of regeneration inside and outside of canopy gap showed that the density of regeneration inside canopy gaps was 30% higher than that outside canopy gaps. The specific species regeneration response to canopy gap varied greatly. *Pinus koraiensis, Picea jezoensis Fraxinus mandshurica, Juglans mandshurica* and *Acer mono* generally did not response to canopy gap disturbance. The Regeneration Importantce Value (RIV) of *Abies nephrolepis, Ulmus Japonica* increased with canopy gap disturbance. RIV of *Tilia amurensis, Acer madshurica and Ulmus laciniata* decreased with canopy gap disturbance. Canopy gap disturbance was not strong enough to result in the regeneration of some species of shade intolerance such as *Larix olgensis, Betula platyphylla*.

Key words: Broad-leaved Korean pine forests, Canopy gap, Regeneration

Introduction

Broad-leaved Korean pine forest is a climax forest in temperate zone of Northeastern China. Its characteristic has high stability and productivity. There were many research works focused on the structure, dynamics and its maintaining mechanism. Research on the forest regeneration was a main approach to understand the forest dynamics[7]. There were many researches on the regeneration of this kind of forest since 1950[5~11]. But few of them were done under the consideration of canopy gap disturbance. Since 1990's, more and more researchers have considered the canopy gap disturbance as a major mechanism to maintain the structure and dynamics of forest[1~4]. It is only at the beginning stage for us to study the forest canopy gap dynamics in China. There were only a few on these studies.

According to these researches, canopy gap disturbance happened commonly in broad-leaved Korean pine forest. Canopy gap disturbance resulted in the diversity of microhabitat in forest and produced suitable regeneration environment for various species. Canopy gap disturbance was recognized as a major driving force to maintain the forest structure and its stability.

Methods

Broad-leaved Korean pine forest is a major type of forests and distributes widely between elevations of 500 m and 1100 m in Changbai Mountain. Affected by the monsoon, the climate of the region is present as the features a temperate continental mountainous climate with a cold weather during the long winter and short cool summer. The mean annual temperature ranges from 2°C to 4°C. Average annual precipitation is 630~780 mm and mainly distributes in July and in August. The period of accumulated temperature of above 10°C is about 1500 days and frost-free period is 100~120 days.

The soil type is the mountainous dark brown forest soil. The typical broad-leaved Korean pine forest is multi-storied and uneven-aged, which has abundant species and complex structure. The dominant tree species are *Pinus koraiensis, Tilia amurensis, Fraxinus madshurica, Quercus mongolica, Ulmus Japonica and Acer mono.* The coverage of shrub layer and herb layer is 0.4 and 0.8 respectively.

Two transacts were selected for sampling in the virgin broad-leaved Korean pine forest in the Changbai Mountain National Reserve. Beginning at randomly chosen points, transacts extended along the parallel direction to the long axis of each suitable study area. According to the investigating in these transacts, when the canopy gap was met, the area of canopy gap, number of fallen trees, death cause of tree, decayed class of fallen logs were recorded.

The area of canopy gap was estimated in 3 ways according to the different definition. Actual gap area was the area of open ground, which was formed by one or several big tree's death. This kind of gap can be filled up and its area is changeable because of the influence of canopy's side-growth. Expanded gap area is the area enclosed by

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the tree stems around canopy gap, which is unchangeable with the time. Maximum gap area is the area enclosed by the tree crown around canopy gap, which includes all the area influenced by canopy gap directly or indirectly. Maximum gap area is a very important index for defining gap model of simulating area.

The area for each gap intersected by transacts was estimated by fitting gap length (largest distance between two gap edges) and width (largest distance perpendicular to the length) for an ellipse in the formula (most gaps are shaped more or less like an ellipse). Crown width of 4 trees at the points of ellipse's poles was measured for estimating the area of actual gap and maximum gap.

According to the cause of tree death, disturbance was classified into 3 types: breakage of live trees, uprooting of live trees and standing dead trees. Decayed status of gap makers was classified into 4 classes: Class A : the bark and twigs were intact; Class B: bark and twigs were partly absent; Class C: bark was absent and sapwood began to decay; Class D: sapwood decayed and heartwood fragmented.

Results and analysis

Canopy gap characteristics

The characteristics of canopy gap of broad-leaved Korean pine forest were listed in Table 1.

Table 1. The characteristics of canopy gap of broad-leaved Korean pine forest

No	Area of canopy gap /m^2			Gap makers					
	AG	EG	MG	Number	DBH /cm	Max. DBH /cm	Decayed class	Species	Cause of death
1.03	36.5	230.0	572	5	26.5	36.0	B	*Abies nephrolepis*	S
1.04	123.8	399.0	777	5	42.0	97.0	C	*Tilia amurensis*	F
1.05	18.5	252.9	549	2	31.0	31.0	D	*Tilia amurensis*	F
1.06	44.7	275.5	631	1	62.0	62.0	C	*Tilia amurensis*	F
1.07	56.5	376.8	622	4	30.3	47.5	C	*Tilia amurensis*	F
1.08	30.5	297.0	593	3	24.6	48.0	A	*Pinus koraiensis*	F
1.09	53.0	234.0	518	4	38.5	64.0	A	*Tilia amurensis*	S
1.1	46.5	188.4	414	3	64.5	86.0	A	*Quercus mongolica*	S
1.11	24.5	164.3	412	2	39.0	60..0	B	*Tilia amurensis*	F
1.12	27.7	204.1	518	3	40.0	64.0	B	*Tilia amurensis*	F
1.13	135	438.0	795	2	61.0	61.0	B	*Tilia amurensis*	B
1.14	13.5	132.0	387	2	64.0	64.0	D	*Tilia amurensis*	B
1.15	169.0	410.0	730	3	43.0	52.0	B	*Pinus koraiensis*	B
1.16	562.8	745.0	1055	2	88.0	109.0	A	*Ulmus japonica*	F
1.17	416.0	566.0	827	4	48.0	85.0	A	*Tilia amurensis*	F
1.18	406.8	674.0	1017	2	71.0	91.0	A	*Tilia amurensis*	B
1.19	904.0	1275.0	1664	1	77.0	77.0	A	*Tilia amurensis*	F
1.2	240.0	395.0	659	3	57.0	85.0	A	*Pinus koraiensis*	B
1.21	237.0	360.0	628	1	24.0	24.0	A	*Ulmus japonica*	F
1.22	298.0	491.0	747	4	42.0	81.0	B	*Pinus koraiensis*	S
1.23	302.6	446.0	880	1	63.0	63.0	B	*Pinus koraiensis*	F
1.24	219.0	327.0	572	2	51.0	51.0	C	*Pinus koraiensis*	F
1.25	133.0	230.0	571	2	55..0	68.0	C	*Tilia amurensis*	S
2.01	109.0	252.0	439	3	32.0	50.0	D	*Pinus koraiensis*	B
2.02	56.0	182.0	388	2	27.0	30.0	D	*Acer mono*	B
2.03	109.0	310.0	597	2	45.0	48.0	A	*Betula platyphylla*	F
2.04	390.0	767.0	1356	2	56.0	60.0	D	*Ulmus japonica*	F
2.05	376.0	779.0	1272	2	47.0	50.0	C	*Pinus koraiensis*	F
2.06	104.0	382.0	786	1	50.0	50.0	C	*Pinus koraiensis*	B
2.07	437.0	910.0	1500	2	52.0	55.0	B	*Pinus koraiensis*	B
2.08	149	377	699	2	62	80	D	*Pinus koraiensis*	B
2.09	216	703	1 175	4	47	50	B	*Tilia amurensis*	B
2.10	143	340	567	2	47	55	C	*Tilia amurensis*	S
2.11	28	247	640	1	58	58	D	*Pinus koraiensis*	B
2.12	61	212	397	1	54	54	D	*Tilia amurensis*	B
2.13	99	286	670	2	52	52	C	*Tilia amurensis*	B
2.14	26	165	415	1	56	56	D	*Pinus koraiensis*	B
2.15	240	490	803	2	76	76	D		B

Continued to Table 1.

No.	Area of canopy gap /m^2			Gap makers					
	AG	EG	MG	Number	DBH /cm	Max. DBH /cm	Decayed class	Species	Cause of death
2.16	106	353	697	1	80	80	B	*Tilia amurensis*	F
2.17	78	207	390	4	38	54	D	*Tilia amurensis*	F
2.18	567	939	1 373	2	70	81	B	*Pinus koraiensis*	F
2.19	200	343	501	3	24	38	D	*Quercus mongolica*	B
2.20	57	199	431	1	38	38	B	*Pinus koraiensis*	B
2.21	155	720	1 083	3	52	56	D	*Quercus mongolica*	F
2.22	294	775	1 229	6	43	57	C	*Quercus mongolica*	F
2.23	135	373	647	3	38	52	A	*Betula platyphylla*	F
2.24	98	385	628	4	34	38	D	*Tilia amurensis*	F
2.25	164	503	863	4	63	84	A	*Quercus mongolica*	S
2.26	268	644	1 005	4	41	68	A	*Tilia amurensis*	F
2.27	169	412	728	4	31	32	B	*Tilia amurensis*	B
2.28	316	660	984	5	40	66	C	*Pinus koraiensis*	F
2.29	330	854	1 140	4	55	110	A	*Quercus mongolica*	F
2.30	148	493	684	3	56	100	B	*Ulmus japonica*	B

Notes: AG: Actual gap area, EG: Expanded gap area, MG: Maximum gap area F: breakage or uprooting of live trees, S: standing dead trees, B: Natural death

Canopy gap area is a very important index to estimate the disturbance intensity, and it has a great influence on tree growth and regeneration. Table 2 showed that the gaps area with an actual gap area less than 250 m^2 took up more than 70% of total. The area of most expanded gap ranged between 100 m^2 and 500 m^2, which took up about 70% of total. Maximum gap area ranged from 300 m^2 to 900 m^2, and mainly ranged between 500 m^2 and 700 m^2. Integrating the area of both expanded gap and maximum gap, we thought the simulating gap area of broad-leaved Korean-pine forest should be between 500 m^2 and 900 m^2. This means to take the expanded gap area as the lower limit and the maximum gap area as the upper limit.

The canopy gap area was mainly related to total basal area instead of the numbers of gap makers. The relationships among actual gap area, expanded gap area, maximum gap area with the total basal area of gap makers could be expressed by the following equations:

Y_{ag}=9.7151X_{ba} +3505.4 r=0.606

Y_{eg}=8.0553X_{ba} +1955.9 r=0.641

Y_{mg}=5.1458X_{ba} +1531 r=0.579

Where: Y_{ag}, Y_{eg}, and Y_{mg} are Actual gap area, Expanded gap area, and Maximum gap area respectively, X_{ba} is total basal area of gap makers.

The value of r showed that expanded gap area had a closest relationship with total basal area of gap makers.

Gaps were generally formed by different disturbance regimes. Table 2 showed that nearly gaps of 50% were formed by natural death of old trees and that of 40% was formed by wind disturbance. Wind disturbance was a major disturbance regime.

Table 2. Canopy gap area of broad-leaved Korean pine forest

Numbers	Actual gap /m^2	Percentage %	Numbers	Expanded gap /m^2	Percentage %	Numbers	Max. Gap /m^2	Percentage %
11	<50	20.0	0	<100	0	2	<300	3.6
8	50~100	14.5	8	100~200	14.5	9	300~500	16.4
11	100~150	20.0	11	200~300	20.0	21	500~700	38.2
5	150~200	9.0	12	300~400	21.8	10	700~900	18.2
5	200~250	9.0	7	400~500	12.7	5	900~1 100	9.0
3	250~300	55.0	2	500~600	3.6	3	1 100~1 300	5.5
3	300~350	55.0	3	600~700	5.5	3	1 300~1 500	5.5
2	350~400	3.6	6	700~800	10.9		1 500~1 700	
6	>400	10.9	4	>800	7.2		>1 700	

Varied numbers of trees formed different gaps. Most gaps were formed by 2 gap makers, which took up 35% of total gaps. Only a few gaps were formed by gap makers exceeded 5 trees. On average, there were 2.65 gap makers in one gap. Tree species of gap makers were almost the same as the dominant tree species of forest. They were *Pinus koraiensis, Tilia amurensis, Fraxinus madshurica, Quercus mongolica, Ulumus Japonica and Acer mono.* The gap makers 32% were *Pinus koraiensis* and 28% was *Tilia amurensis.*

Distribution of diameter class showed that the DHB of most of gap makers was less than 70 cm and mainly

ranged between 50 cm and 60 cm. Gap makers of *Pinus koraiensis* occurred in different class and DBH equally was 43 cm on average. Most of gap makers of *Tilia amurensis* were the trees with a DBH between 60 cm and 70 cm, and the average DBH was 51.9 cm. The gap makers of *Quercus mongolica* were the biggest and the average DBH was 57.1 cm. *Acer mono* was the smallest gap maker with DBH of 23.2 cm on average.

Table 3. The DBH distribution of the gap makers

Species	Diameter class /cm								Total	Percentage %
	<30	30~40	40~50	50~60	60~70	70~80	80~90	>90		
Pinus koraiensis	9	11	6	12	4	1			47	32.0
Tilia amurensis	3	5	7	8	12	2	4	2	41	28.0
Quercus mongolica	1	2	1	3	1	1	2	1	12	8.2
Ulmus japonica	2	1	1	1	2		2	2	9	6.2
Betula platyphyla	2	3	2	1					8	5.5
Abies nephrolepis	4	3	1						8	5.5
Fraxinus mandshurica	2	0	2						4	2.8
Acer mono	8	1	0						9	6.2
Other species.	1	2	3						6	4.2
Total	33	29	23	25	19	4	8	5	146	
Percentage %	22.8	19.8	15.7	17.1	13	2.7	5.5	3.4		100.0

Although there were various sizes of gap makers in one gap, the biggest one is the most important one for determining the characteristics of gap. Table 4 showed the DBH distribution of maximum gap maker.

Table 4. The DBH distribution of maximum gap maker

Species	Diameter class /cm								Total	Percentage %
	<30	30~40	40~50	50~60	60~70	70~80	80~90	>90		
Pinus koraiensis		1	4	8	3		3		19	34.5
Tilia amurensis		3		5	8	2	2	2	22	40.0
Quercus mongolica		1		2	1	1	1	1	7	12.7
Ulmus japonica	1				1			2	4	7.3
Betula platyphylla			1	1					2	3.6
Acer mono		1							1	1.9
Total	1	6	5	16	13	3	6	5	55	100.0
Percentage %	1.9	10.9	9.1	29.1	23.5	5.5	10.9	9.1		

The DBH of maximum gap makers of broad-leaved Korean pine forest ranged essentially between 50 cm and 70 cm, which took up 50% of total. Gap makers of which DBH were less than 40 cm or bigger than 80 cm only took up 13% and 20%, respectively. Most of maximum gap makers were *Tilia amurensis* and *Pinus koraiensis*, which took up 40% and 34.5% of total maximum gap makers respectively.

Decayed class of maximum gap makers reflected the chronological order of gap formation. The number of maximum gap maker in every decayed class was almost the same. This meant the gaps of broad-leaved Korean pine forest were formed in a stable rate during a long period. The area of canopy gaps formed in different stage varied slightly. Actually, broad-leaved Korean pine forest was a dynamic patch mosaic. This partly explained why broad-leaved Korean pine forest could exist steadily.

Regeneration

The density of seedlings was 3300 stems inside canopy gap and 2328 stems under canopy for area (hm^2) respectively(Table 5). The former was 30% higher than the latter. Most of dominant species, such as *Pinus koraiensis, Abies nephrolepis, Fraxinus mandshurica* and *Ulmus japonica*, regenerate better inside canopy gap than that under canopy. Some species such as *Tilia amurensis, Ulmus laciniata* are more easily to regenerate under canopy. There was no significant difference for some species such as *Acer mono*.

For species of shade intolerance such as *Populus spp, Betula platyphyla, Larix olgensis*, and so on, there was no regeneration both inside gaps and under canopy. This indicated that canopy gap disturbance was not strong enough to result in the regeneration of shade intolerance species.

Based on the RIV difference, response of species to canopy gap could be classified into 3 types. Type 1 was the species, which had no response to canopy gap; i.e. the RIV difference value was very low. These species included *Pinus koraiensis, Picea jezoensis, Fraxinus mandshurica, Juglans mandshurica and Acer mono*. Type 2 had positive response to canopy gap, i.e. the RIV difference value was very high. These species included *Abies*

nephrorepis, Ulmus japonica, Acer tegmentosum. Type 3 had negative response, i.e. the RIV difference value was negative. These species included *Tilia amuensis, Ulmus laciniata, Acer pseudo-sieboldianum, Acer mandshuricum.* Other species were not present in the table because there was no regeneration both inside gap and under canopy, i.e. they could not regenerate within forest. This indicated that canopy gap disturbance was not strong enough to result in the regeneration of these species of shade intolerance such as *Populus spp, Betula platyphyla, Larix olgensis,* and so on.

Table 5. Regeneration characteristics in canopy gaps and under canopy

Species	In Canopy gap				Under Canopy			
	Density stem/hm^2	Relative Density %	Frequency	Relative frequency	Density stem/hm^2	Relative Density %	Frequency	Relative frequency
Pinus koraiensis	125	3.8	3	4.8	57	2.5	1.7	3.6
Picea jezoensis	75	2.3	2	3.2	14	6.0	0.5	1.1
Abies nephrorepis	650	19.7	7	11.3	129	5.5	2.8	5.9
Tilia amuensis	175	5.3	2	3.2	285	12.2	5.0	10.6
Fraxinus mandshurica	25	0.8	1	1.6	0	0.0	0.0	0.0
Juglans mandshurica	50	1.5	2	3.2	0	0.0	0.0	0.0
Ulmus japonica	500	15.0	11	17.7	143	6.1	5.0	10.6
Ulmus laciniata	0.0	0.0	0.0	0.0	187	8.0	4.5	9.6
Acer mono	450	13.6	11	17.7	414	17.8	11.0	23.0
Acer pseudo-sieboldianum	500	15.0	11	17.7	671	28.8	11.0	23.0
Acer tegmentosum	650	19.7	8	12.9	228	9.8	6.0	12.8
Acer mandshuricum	100	3.0	4	6.5	200	8.6	5.7	12.1
Total	3300		62		2 328		47.0	

Table 6. The relative importance values in canopy gaps and under canopy

Species	In canopy gap		Under canopy		RIV difference
	RIV	Ordination	RIV	Ordination	
Pinus koraiensis	4.3	7	3.1	9	1.2
Picea jezoensis	2.8	9	0.9	10	1.9
Abies nephrorepis	15.5	5	5.7	8	9.8
Tilia amuensis	4.3	8	11.4	3	-7.1
Fraxinus mandshurica	1.2	11	0	11	1.2
Juglans mandshurica	2.4	10	0	12	2.4
Ulmus japonica	16.4	2	8.3	7	8.1
Ulmus laciniata	0	12	8.8	6	-8.8
Acer mono	15.6	4	5.4	2	0.2
Acer pseudo-sieboldianum	16.4	1	25.9	1	-9.5
Acer tegmentosum	16.3	3	11.3	4	5
Acer mandshuricum	4.7	6	10.4	5	-5.7

Note: RIV- Regeneration importance value

Conclusions

The actual gap area of more than 70 % was smaller than 250 m^2, expanded gap area of 70 % ranged between 100 m^2 and 500 m^2. The area of most maximum canopy gap ranged between 300 m^2 and 900 m^2. The simulating area of canopy gap was 500 m^2 to 900 m^2.

Gap of 50% was formed by natural death of old trees and that of 40% formed due to the wind disturbance. Wind disturbance was a major force in forming the canopy gaps.

The gaps formed by 2 gap makers took up 35 % of total gaps. There were gap makers of 2.56 in one gap on average.

Tree species of gap makers was almost as same as the dominant tree species of forest. They were *Pinus koraiensis, Tilia amurensis, Quercus mongolica, Ulumus Japonica and Acer mono.* Most of maximum gap makers were *Tilia amurensis* and *Pinus koraiensis*, which took up 74%.

The DBH of most gap makers was less than 70 cm, that of 40% was less than 40 cm. Maximum gap makers of fifty percent ranged between 50 cm and 70 cm.

The distribution of maximum gap makers on different decayed class was nearly equal. The gaps were formed at a stable rate in broad-leaved Korean pine forest over a long period. Regeneration inside canopy gap was better than

that under canopy. Seedling density of the former was 30% higher than that of the latter.

Based on the RIV difference, response of species to canopy gap could be classified into 3 types. They were no response, positive response, and negative response.

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